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FEASIBILITY OF MOSSBAUER SURVEY METER FOR HYDROCARBON AND MINERAL RESERVES

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The feasibility of developing a sensitive and economical geophysical prospecting device based on Mossbauer phenomenon has been studied.

16. Abstract

The feasibility of developing a Mossbauer survey meter for geophysical prospecting has been investigated. Various critical requirements that will have to be met by the source and absorber crystals in such an instrument have been identified. It has been concluded that a survey meter based on (Rh^{103*} (40 keV) → Rh^{103}) isomeric transition is feasible and should be developed.

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FEASIBILITY OF MOSSBAUER SURVEY METER FOR HYDROCARBON AND MINERAL RESERVES

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INTRODUCTION

The current energy and materials shortages have sparked considerable worldwide interest in prospecting for hydrocarbon and mineral deposits. There are several geophysical prospecting methods currently in use. Prominent amongst them are those based on anomalies in gravitational, geomagnetic, or electromagnetic fields and the elastic properties of soils and rocks associated with oil and mineral deposits. Perhaps the highest current field accuracy is achieved in gravity exploration where modern gravity meters can permit an accuracy up to 0.01 milligal (1 part in 10^8). Such an accuracy, however, is obtainable only with a complicated system of springs and levers which require dimensional stability of a few atomic diameters for an extended period. (However, due to elastic creeps in springs, etc., these instruments sometimes exhibit significant nonlinear drifts, corrections for which cannot be made. The practical consequence of this is a reduction in sensitivity to about 1 part in 10^7 or more.) The reported accuracy of gravity meters on airborne pads is of the order of 1 part in a million, sufficient to detect significant ore and hydrocarbon deposits deep underground. Major drawbacks of current gravity survey techniques are their mechanical complexity and tedious data interpretation. The extreme precision with which Mossbauer spectral lines can be measured presents a comparatively

simpler and lower cost alternative technique of measuring fine gravitational anomalies associated with oil and mineral deposits. The basis of the proposed technique, along with various physical requirements for the source and the absorber crystals, is discussed in the following pages.

BRIEF REVIEW OF CURRENT GEOPHYSICAL PROSPECTING TECHNIQUES

Before proceeding with the Mossbauer gravitometer, a brief review of the presently utilized methods of prospecting and their limitations is given. Current prospecting methods may be divided into two types:

1. Direct Methods: These methods include geologic and photogeologic mapping supplemented by drilling and sampling. If there is a surface evidence of underground minerals - such as soil staining, alteration, or structures in deeply weathered areas - examination and sampling may be all that is necessary to determine if further exploration is warranted. In the absence of obvious ore guides, prospecting can still be based on geological inference. For example, ore minerals genetically associated with certain other minerals of no economic importance can be detected by the presence of the latter. Similarly, float materials (detached fragments of mineralized rock or vein material) usually indicate a bedrock source at some higher point.

2. Indirect Methods: In these methods, geophysical, geochemical, and botanical evidence of subsurface deposits is usually employed. Of all the indirect methods, those based on physical measurements are the most important. The physical measurements are interpreted in terms of subsurface geological conditions. A brief description of commonly used geophysical methods follows:

a. Magnetic Methods: Both aerial and surface magnetic surveys are used extensively to detect magnetic ores and others which exist in conjunction with magnetic ores. The accuracy of the precision Schmidt and compensation type variometers is of the order of ±5 gammas. The flux-gate and the proton free precession magnetometers are usually capable of an accuracy of the order of ±10 gammas (ref. 1). These sensitivities are rather low. However, a Josephson magnetic gradiometer may be able to detect much smaller magnetic anomalies (i.e., about $3 \times 10^{-12} \frac{\text{gauss}}{\text{cm}^2}$ per $(\text{Hz})^{\frac{1}{2}}$ (ref. 2).

b. Seismic Methods: For the last quarter of a century, the exploration for oil and gas has depended on seismic methods. However, the success ratio of exploratory wells based on seismic surveys is usually between 15 and 20 percent. Even today, the seismic explorers depend on the black magic of the so-called bright spots technique for oil/gas exploration.

c. Electrical Methods: Sulphur and graphite are usually detected by self potential measurements. Water bearing formations, hydrocarbon deposits, and conducting minerals usually require a dc or low frequency ac current source. Both types of measurements require contact with the earth, which is not always possible.

d. Gravity Methods: These methods are based on the fact that the density of hydrocarbon bearing rocks is different from the normal soil as well as ore-carrying soil. These differences in subsurface soil density are reflected in the values of local gravitational attraction. As indicated earlier, the gravity meters are the most sensitive currently known means of detecting subsoil deposits. Gravimeters capable of a resolution of the order of 0.01 milligal are currently available (ref. 3).

THE BASIS OF THE PROPOSED MOSSBAUER GRAVITOMETER

The Mossbauer gravitometer is based on the principle of equivalence in the general theory of relativity, according to which the energy of a source photon of energy E will change by $(\frac{E}{c^2} gh)$ as it arrives at the absorber station located at a vertical distance h above the source. (Any fluctuation in g will be accompanied by a corresponding fluctuation in the photon energy loss.) In the case of certain isomeric radionuclides - such as Rh^{103*}, Ag^{109*}, and In^{113*} - the change in photon energy per meter travel against the gravitational field may be large enough to take the photon off resonance at the absorber atom (ref. 4). Application of a finely controlled modulation field, superimposed on a dc magnetic field, to the absorber atom can restore the resonant absorption condition for certain hyperfine levels. The magnitude of the modulating field needed for such a restoration will depend upon the local gravitational field. Thus a measurement of the "resonance" magnetic field is expected to give information about the gravitational potential distribution, which may be used to locate oil/mineral deposits.

The basis of the proposed gravitometer is illustrated in figures 1 and 2. A source photon of energy E, after traveling against a gravitational attraction g through a distance h, will loose an energy ΔE:

$$\Delta E = \frac{E}{c^2} \int_R^{R+h} \frac{G M_E}{r^2} dr$$

$$\cong \frac{E}{c^2} gh \qquad (1)$$

The fluctuation in $\Delta E = \delta E$, resulting from a fluctuation δg in g may be calculated as follows:

$$(\Delta E \pm \delta E) = \frac{E}{c^2}(g \pm \delta g)\, h \tag{2}$$

$$\therefore \frac{\delta E}{\Delta E} = \frac{\delta g}{g} \tag{3}$$

$$\therefore \delta E = \Delta E \left(\frac{\delta g}{g}\right)$$

$$= \Delta E \times 10^{-6} \quad \left(\text{for } \frac{\delta g}{g} = 10^{-6}\right)$$

$$= \left(\frac{E}{c^2} gh\right) \times 10^{-6}$$

$$= E \times 10^{-22} \quad \text{per meter at the surface of earth}$$

$$= 4 \times 10^{-18} \text{ eV/meter} \quad [\text{for } Rh^{103*} \text{ (40 keV)}]^{\dagger} \tag{4}$$

Now using the Heisenberg uncertainty principle (ref. 5), one obtains:

$$\Gamma\left[Rh^{103*}\left(\frac{7}{2}^{+}\right)\right] = 1.9 \times 10^{-19} \text{ eV} \tag{5}$$

i.e., $\frac{\delta E}{\Gamma} = 21$ for Rh^{103*} (40 keV) per meter source-absorber separation. (6)

Thus a change in 40 keV photon energy resulting from a 1 ppm fluctuation in local g equals 21 times the natural width of the isomeric level in Rh^{103}. Such a change should be detectable by means of magnetic modulation.

Figure 2 provides a conceptual explanation of how such a system might work. In this figure, it has been assumed that the photon energy depends on the gravitational potential but the nuclear levels, measured by an observer at rest with

† Rh^{103} (40 keV) has been used for illustrative purposes only.

respect to the nucleus and situated in the same gravitational potential, remain unchanged. This assumption is based on the weakness of the gravitational interaction as compared with the nuclear and electromagnetic forces.

REQUIREMENTS FOR A MOSSBAUER GRAVITOMETER

It is obvious from equations (4) and (5), in the previous section, that the line width of the Mossbauer state must be less than the fluctuation in the photon energy resulting from a 1 ppm change in the gravitational force if the Mossbauer gravitometer is to detect a 1 ppm gravitational anomaly. For the sake of clarity, the conditions governing the Mossbauer level widths will be discussed in terms of a specific nuclide (Pd^{103} - Rh^{103}).

Consider a crystal of very pure rhodium metal at very low temperature. At absolute zero, the electronic and nuclear spins are all alined by their magnetic interactions. If the crystal is perfect, the local magnetic fields seen by the different nuclei will be the same magnitude and all nuclei will be oriented the same way relative to the local field. The magnetic shift of the resonance frequency will therefore be the same for all nuclei and they will remain in perfect resonance with one another. The same applies to local electrical fields. However, an actual rhodium crystal at low (but non-zero) temperature will have some randomly distributed impurities/dislocations or misalined spins resulting in broadening of the line. These and other sources of line broadening are described below.

1. Electron-nuclear Interaction: The main broadening effect due to an impurity, dislocation, or misalined spin arises from the magnetic dipole-dipole interaction between the electron and the nuclear spins. If n is the atomic density in the crystal and f_1 is the fraction of sites occupied by the defects or misalined spins, the level broadening $\Delta\Gamma_{e-n}$ is given by the following expression (refs. 6 and 7).

$$\Delta\Gamma_{e\text{-}n} \simeq 2\,\frac{\mu_e \cdot \mu_n}{d^3}$$

$$\simeq \mu_e \cdot \mu_n \; n \; f_1 \qquad (7)$$

In the case of Rh^{103}, μ_n = 0.0879 nuclear magneton and μ_e = 2 Bohr magnetons. Thus for $\Delta\Gamma_{e\text{-}n} \lesssim \Gamma_{(natural)}$ in Rh^{103*}, f_1 must be $\lesssim 10^{-10}$. An f_1 value of 10^{-10} for misalined spins corresponds to an electron spin system temperature of $\simeq 10^{-2}$ K° because the electronic spins are oriented chiefly by their near neighbor dipoler interactions (ref. 7).

2. Internuclear Interactions: Broadening due to impurities and wrongly oriented nuclei must also be considered. It must also be remembered that Rh^{103*} (40 keV) itself is an impurity in the Rh^{103} crystal. For the level broadening due to such impurities not to exceed the natural width, the impurity fraction f_2 is estimated to be $\lesssim 10^{-7}$. As the limit on the wrong nuclear spin orientations, an f_2 value of 10^{-7} corresponds to a nuclear spin temperature of $\sim 10^{-3}$ K° (refs. 7 and 8).

3. EFG - nuclear quadrupole Interactions: The source/absorber crystals should be sufficiently free from random charged impurities and mechanical strains to produce an electric field gradient (EFG) at a Rh^{103} nucleus of no larger than 10^{10} volts/m^2 in order to keep line broadening ΔEQ within acceptable limits. This can be seen from the following calculation.

$$\Delta EQ = \frac{1}{4}\,(Qe\,\partial^2 V/\partial Z^2)$$

$$= 2.5 \times 10^{-19} \text{ eV} \qquad \left(\text{for } Q = 10^{-28} \text{ m}^2 \text{ and } \partial^2 V/\partial Z^2 = 10^{10}\ \frac{\text{volts}}{\text{m}^2}\right) \qquad (8)$$

An EFG value of $\lesssim 10^{10}$ volts/m^2 can be met by an impurity level $\lesssim 10^{-10}$ required to keep down electron-nuclear broadening.

4. Miscellaneous Sources of Line Broadening: Pd^{103} atoms will act as random magnetic impurities in the source crystal, leading to the source line broadening. Also the magnetic interaction between the ground state and the Mossbauer state will lead to level broadening in both the source and the absorber atoms. These sources of line broadening can, however, be eliminated by imposing a dc magnetic field on the source and absorber crystals. Such a spin polarizing field will also provide the added advantage of simplifying the Mossbauer spectrum as discussed in Appendix 1.

Of the various sources of line broadening discussed above, it appears that the purity/perfection requirement will be the most difficult to meet. Besides broadening the level widths by mechanisms 1 → 3, defects/impurities can also increase line widths via inhomogeneous chemical shift of the Mossbauer line. However, it is possible to use a specially selected radio frequency field to cancel out such inhomogeneous shift (ref. 9).

In addition to these basic sources of line broadening, the source-absorber vertical separation must not change by more than 1 ppm if the magnetometer is to maintain a sensitivity of $\frac{\Delta g}{g} = 10^{-6}$. (See equation (4).)

All these factors affecting line width are summarized in figure 3.

PROPOSED DESIGN OF A MOSSBAUER GRAVITOMETER

Since Rh^{103*} (40 keV) isomer state has been used as a model for calculations so far, the following design will also be based on this state. A typical source-absorber arrangement capable of a resolution ~1 ppm is illustrated in figure 4. Such a system would be based on the $Pd^{103} \rightarrow Rh^{103*}$ transition. The Rh^{103*} (40 keV) transition to the ground state is strongly

converted, giving rise to K electrons and the accompanying X-rays which can serve as the basis for resonance fluorescence detection. Figure 5 shows further details of Rh^{103*} (40 keV) decay scheme. For an annular detector subtending 30-40 percent of the total solid angle at the absorber, one expects a counting rate of the order of 60 pm for a $\frac{\Delta h}{h}$ uncertainty ~ 1 ppm (for a Pd^{103} source strength ~ 1.5 curies).† The reasons for the choice of ($Pd^{103} \rightarrow Rh^{103}$) transition as the basis for a typical Mossbauer gravitometer design are listed below.

1. Pd^{103} source of required strength can be easily produced by Rh^{103} (p, n) Pd^{103} or Rh^{103} (d, 2n) Pd^{103} reactions. Furthermore, Pd^{103} can be rather easily separated from Rh^{103} and other reaction products by an ion-exchange process. (See Appendix 2.)

2. Low energy of X/γ-rays and the electrons involved in $Pd^{103} \rightarrow Rh^{103}$ decay ensure freedom from radiation damage to the crystal lattice.

3. Low photon energy (40 keV) and high Debye temperature in Rh^{103} (512 ± 17 K°) ensure a large recoilless fraction ($f \simeq 0.7$) in $Rh^{103*} \rightarrow Rh^{103}$ (g.s.) transition.

4. Prospects for growing very pure (impurity/defect concentration $\leq 10^{-10}$ (7×10^{22}) = 7×10^{12}/cc) single crystals in Rh^{103} and Pd^{103} are reasonably high. (This conclusion is based on comparison with the silicon crystal purity problem (ref. 10).)

A typical experimental configuration for a Mossbauer survey meter based on excitation of long-lived nuclear states is illustrated in figure 6.

† This is true for isotropic distribution of the 40 keV radiation at the source. For a polarized source, with sharply forward peaked distribution, considerably higher counting rates may be expected.

One aspect of equations (1) and (4) deserves a few words of explanation. As long as the source and the absorber crystals experience identical accelerations, the resonance fluorescence conditions at the absorber will be affected only by the gravitational potential difference (E/c^2 gh) between them. However, any relative motion between them will affect the photon energy at the absorber. It is therefore necessary that all extraneous forces that can induce relative motion between the source-absorber crystals be eliminated/minimized or otherwise allowed for in the subsequent data analysis. In the presently envisioned configuration, the source-absorber crystals will be mounted on a rigid rod maintained at a constant temperature (see fig. 6) to minimize their relative motion and the entire assembly will be mounted on an inertial platform to maintain parallelism with the local normal to keep constant vertical separation.

CONCLUDING REMARKS

A feasibility study of developing a Mossbauer survey meter based on resonant excitation of isomeric states has been conducted. Detailed calculations have been made for specific transition ($Rh^{103*} \rightarrow Rh^{103}$) and critical requirements, that must be met for a succesful development, identified. The purity/perfection of the source/absorber crystals has been found to be the most important factor governing the level widths. Prospects for growing single crystals of required perfection/purity appear to be reasonably high on the basis of similar experience with silicon crystals. The consideration of dilute magnetic impurities in the source/absorber crystal dictated the need for a polarizing magnetic field. Such a hyperfine field will also have the added advantage of simplifying the Mossbauer spectrum (i.e., four lines instead of fourteen expected for a $\frac{7}{2}^+ \xrightarrow{E_{III}} \frac{1}{2}^-$ transition). In view of the positive

findings of this study, it is recommended that the development of a prototype survey meter based on Mossbauer resonance phenomenon in (Rh^{103*} (40 keV) → Rh^{103}) transition be undertaken.

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APPENDIX 1

THE PROBABILITY OF MULTIPOLE EMISSION AND ABSORPTION

In the wave zone of the source radiation, the electromagnetic energy incident per second on a surface element $R^2 \, d\Omega$ around the direction (θ, φ) is given by the following expression:

$$U(\Omega) \, d\Omega = |S| \, R^2 \, d\Omega \tag{1}$$

where S is the Poynting vector. The energy in a pure electric multipole radiation field of the order ℓ, m with the amplitude $a_E(\ell, m)$, emitted per second into a solid angle element $d\Omega$ is given by $U_E(\ell, m; \Omega) \, d\Omega$, where

$$U_E(\ell, m; \Omega) = \frac{c}{2\pi k^2} Z_{\ell,m}(\theta, \varphi) \left| a_E(\ell, m) \right|^2 \tag{2}$$

where k = wave number of the emitted radiation and the angular distribution function $Z_{\ell,m}(\theta, \varphi)$ is given by:

$$Z_{\ell,m}(\theta, \varphi) = \frac{1}{2}\left[1 - \frac{m(m+1)}{\ell(\ell+1)}\right] \left| Y_{\ell,m+1}(\theta, \varphi) \right|^2 + \frac{1}{2}\left[1 - \frac{m(m-1)}{\ell(\ell+1)}\right] \left| Y_{\ell,m-1}(\theta, \varphi) \right|^2 + \frac{m^2}{\ell(\ell+1)} \left| Y_{\ell,m}(\theta,\varphi) \right|^2 \tag{2a}$$

By analogy, the electric multipole radiation associated with transition $J_1 \rightarrow J_2$ may be written as follows:

$$I_{12}(\theta, \varphi; E) = \sum_{m_1=-J_1}^{J_1} \sum_{m_2=-J_2}^{J_2} P_{m_1} \left| C(J_1 J_2 m_1 m_2; \ell m) \right|^2 Z_{\ell,m}(\theta, \varphi) \tag{3}$$

where J_1 = ground state spin

J_2 = excited state spin

ℓ = multipolarity of the transition

P_{m_1} = relative probability of populating the substate m_1

For the special case of Rh^{103} ($\frac{7^+}{2} \xrightarrow{E_{111}} \frac{1^-}{2}$) transition, the following values of the angular distribution function $Z_{\ell,m}(\theta, \varphi)$ are obtained:

$$Z_{3,0}(\theta, \varphi) = \frac{1}{2}\left|Y_{3,-1}(\theta, \varphi)\right|^2 + \frac{1}{2}\left|Y_{3,+1}(\theta, \varphi)\right|^2 \quad (4)$$

$$Z_{3,1}(\theta, \varphi) = \frac{1}{2}\left|Y_{3,0}(\theta, \varphi)\right|^2 + \frac{1}{24}\left|Y_{3,1}(\theta, \varphi)\right|^2 + \frac{5}{12}\left|Y_{3,2}(\theta, \varphi)\right|^2 \quad (5)$$

$$Z_{3,2}(\theta, \varphi) = \frac{5}{12}\left|Y_{3,1}(\theta, \varphi)\right|^2 + \frac{1}{3}\left|Y_{3,2}(\theta, \varphi)\right|^2 + \frac{1}{4}\left|Y_{3,3}(\theta, \varphi)\right|^2 \quad (6)$$

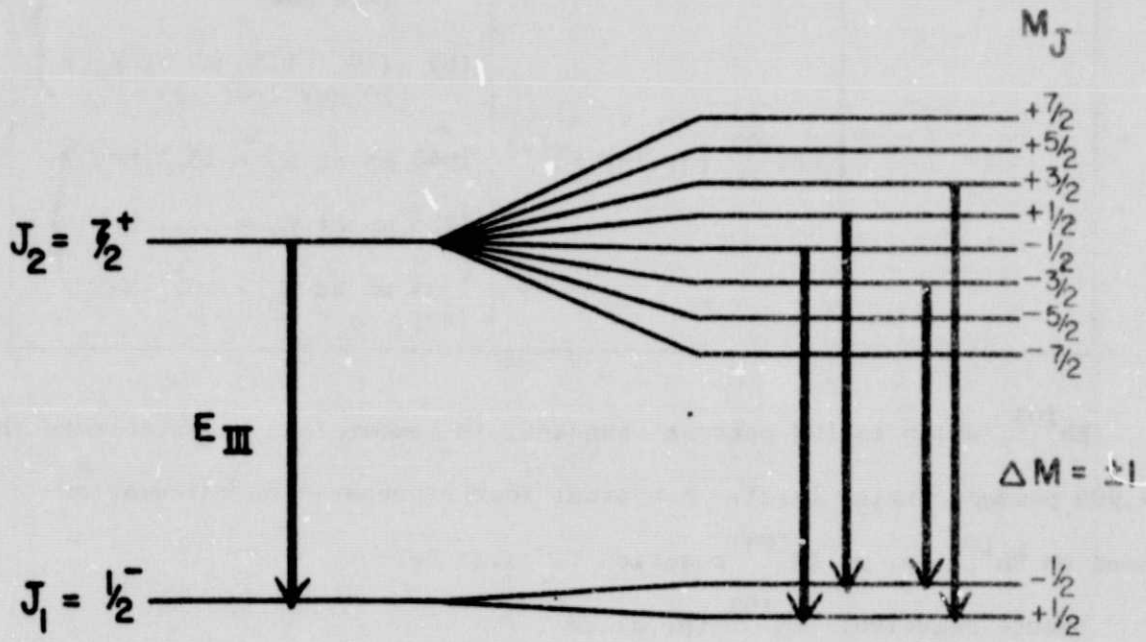
$$Z_{3,3}(\theta, \varphi) = \frac{1}{4}\left|Y_{3,2}(\theta, \varphi)\right|^2 + \frac{3}{4}\left|Y_{3,3}(\theta, \varphi)\right|^2 \quad (7)$$

Substituting the values of appropriate spherical harmonics, one obtains the following values of the angular distribution functions.

$Z_{\ell,m}(\theta, \varphi)$	$\theta = 0$	$\theta = \pi/2$
$Z_{3,3}(\theta, \varphi)$	0	105/256 π
$Z_{3,2}(\theta, \varphi)$	0	70/256 π
$Z_{3,1}(\theta, \varphi)$	224/256 π	7/256 π
$Z_{3,0}(\theta, \varphi)$	0	84/256 π

It is obvious that along $\theta = 0$ direction, only the $Z_{3,1}(\theta, \varphi)$ function has a non-zero value. This implies that only ($\frac{7^+}{2} \pm \frac{3}{2} \xrightarrow{\Delta M = \pm 1} \frac{1^-}{2} \pm \frac{1}{2}$) and

$(\frac{7}{2}^{+} \pm \frac{1}{2} \xrightarrow{\Delta M = \pm 1} \frac{1}{2}^{-} \quad \frac{1}{2})$ transitions will be observed along $\theta = 0$ direction. Thus the Mossbauer spectrum will be considerably simplified if the source/absorber nuclei are polarized by a dc magnetic field parallel to the source-absorber line. The $|\Delta M| = 1$ photons arriving at the absorber crystal will then excite only the $\pm 3/2$ and $\pm 1/2$ sub-levels in the $7/2^{+}$ excited state, resulting in only four lines instead of fourteen lines expected for an unpolarized $7/2^{+} \xrightarrow{E_{III}} 1/2^{-}$ transition. This is illustrated in the figure below



Hyperfine spectrum for polarized source/absorber nuclei in Rh^{103}

APPENDIX 2

PREPARATION OF Pd^{103} RADIOACTIVE SOURCE

There are a number of nuclear reactions that can be used to produce Pd^{103} radionuclides. Some of them are summarized in the following table.

No.	Nuclear Reaction	Cross Section
1	Rh^{103} (p, n) Pd^{103}	(a) (700 ± 40) mb at E_p = 10 MeV (ref. 1) (b) 1100 mb at E_p = 12 MeV (ref. 2)
2	Rh^{103} (d, 2n) Pd^{103}	(a) (58 ± 3) mb at E_d = 14.6 MeV (b) (30 ± 1.5) mb at E_d = 20 MeV (ref. 3)
3	Pd^{104} (n, 2n) Pd^{103}	1040 mb at E_n = 13.1 MeV 1226 mb at E_n = 14.1 MeV 1334 mb at E_n = 15.1 MeV (ref. 4)

Rh^{103}, which is 100 percent abundant, is commercially available to the 99.999 percent purity level. A typical source preparation calculation based on Rh^{103} (p, n) Pd^{103} reaction is given below:

Source reaction: Rh^{103} (p, n) Pd^{103}

σ(p, n) at E_p = 12 MeV: 1.1 barns

Assume a 1 gram Rh target.

The bombardment time, using a beam of 100 microamperes, needed to produce 1 curie of Pd^{103} source is given by:

$$\left[\frac{8 \times 10^{16}}{1.1 \times 10^{-24} \times 6 \times 10^{21} \times 6.25 \times 10^{14}}\right] \text{ secs} \cong 5\tfrac{1}{2} \text{ hours}$$

One must of course make sure that the target thickness is less than the range of 12 MeV protons in rhodium.

The preparation and isolation of carrier free Pd^{103} produced by Rh^{103} (d, 2n) Pd^{103} reaction has been described by several workers (refs. 5, 6, and 7). The procedure used by Gile, et al, (ref. 5) in isolating carrier free Pd^{103} from the target element and 41-day Ru^{103} reaction, is described below. After bombardment for a predetermined time with 20 MeV deutrons, the 1 gram pure rhodium target was fused with excess potassium acid sulphate and the resulting mass leached with water. Insoluble impurities were separated by centrifugation and the decantate was made 6 N in hydrochloric acid by treatment with 12 N hydrochloric acid and sodium chloride and then 5 milligrams of seleneous acid were added to the solution. The resulting solution was treated with excess sulphur dioxide which resulted in precipitation of elemental selenium which carried 99+ percent of Pd^{103} from the solution. The precipitate was washed with water, dissolved, and reprecipitated. The selenium precipitate was dissolved in concentrated sulphuric acid, transferred to an all-glass distilling flask, 9 N hydrobromic acid added and the mixture distilled at 200°C. The residue contained all of the Pd^{103} activity. All these steps can be completed within a period of 1-2 hours. For the extreme purity required for the (Pd^{103} - Rh^{103}) gravitometer, the source thus produced may have to be subjected to a mass spectrometric separation and single crystal growth.

APPENDIX 2

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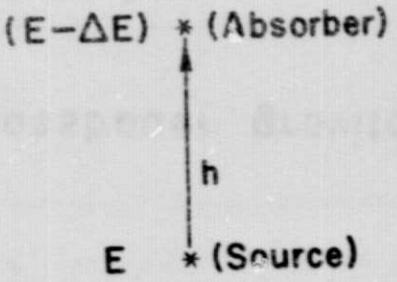
$$\Delta E = \frac{E}{C^2} gh$$

$$(\Delta E \pm \delta E) = \frac{E}{C^2} (g \pm \delta g) h$$

$$\frac{\delta E}{\Delta E} = \frac{\delta g}{g}$$



$$\delta E = 10^{-6} \frac{E}{C^2} gh \quad \left(\text{for } \frac{\delta g}{g} = 10^{-6}\right)$$

$$= E \times 10^{-22} \text{ per meter at earth's surface}$$

$$= 4 \times 10^{-18} \text{ eV/meter for } Rh^{103} \quad (40 \text{ KeV})$$

$$\Gamma \left[Rh^{103^*}\left(\frac{7^+}{2}\right) \right] = 1.9 \times 10^{-19} \text{ eV}$$

i.e. $\frac{\delta E}{\Gamma} = 21$ (for Rh^{103^*} (40 KeV) per meter source–absorber separation.)

Figure 1. Basis of Mossbauer gravitometer

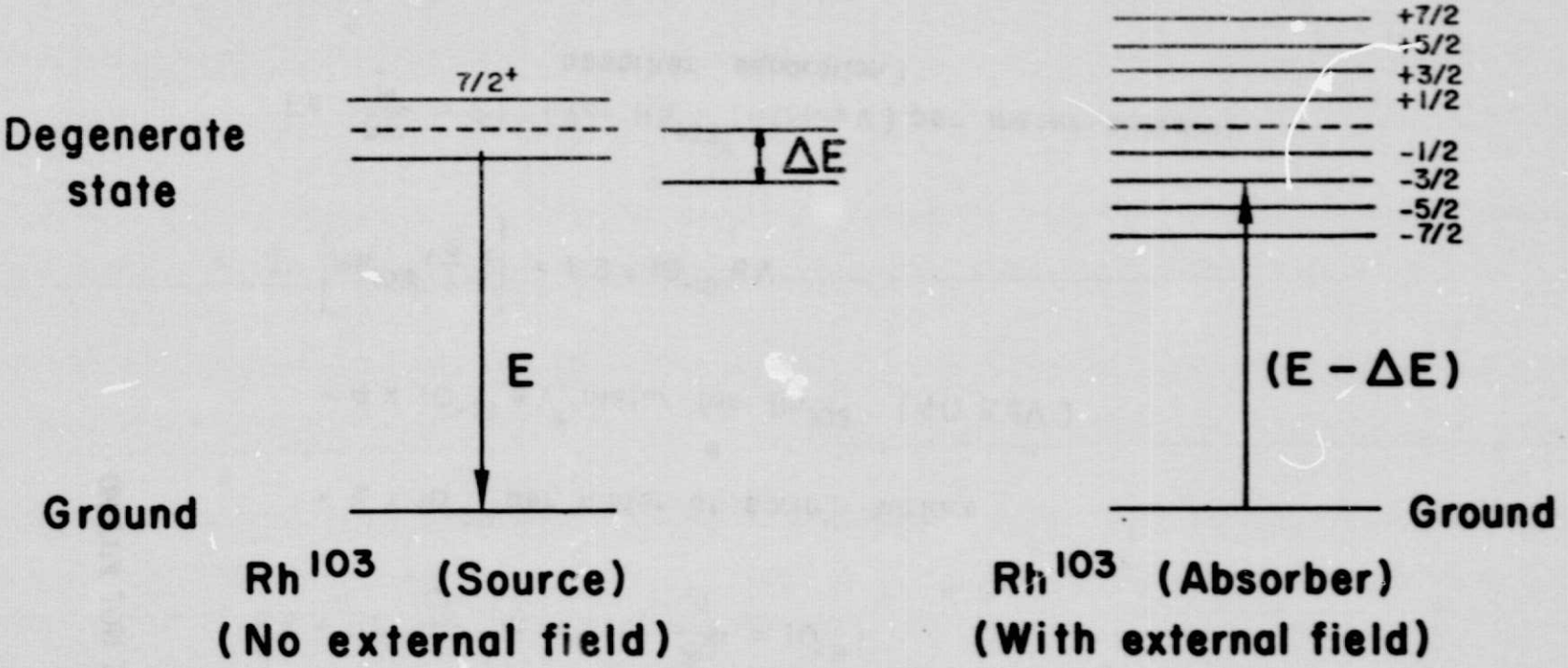
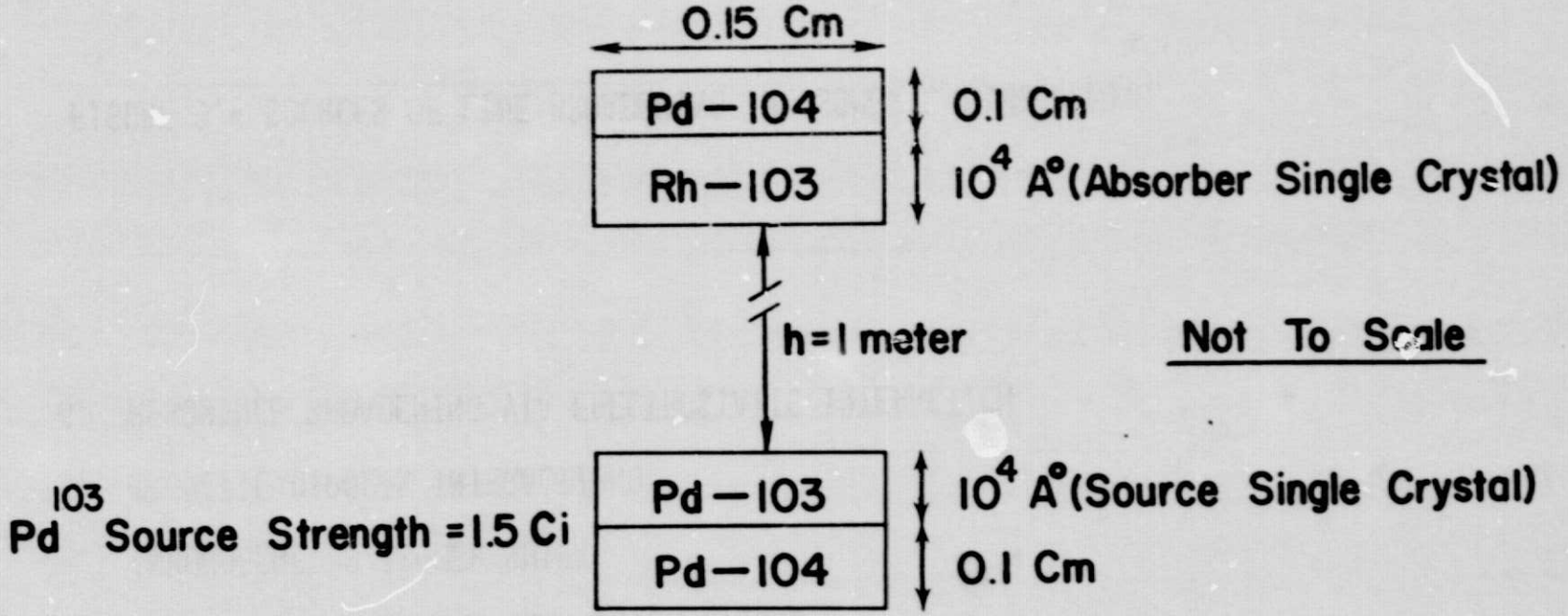


Figure 2. Theory of operation of Mossbauer gravitometer.

THE DEFECTS/IMPURITIES IN THE SOURCE AND ABSORBER CRYSTALS CAN CAUSE LINE BROADENING BY THE FOLLOWING INTERACTIONS.

1. ELECTRON-NUCLEAR INTERACTIONS
2. INTERNUCLEAR INTERACTIONS
3. EFG - NUCLEAR QUADRUPOLAR INTERACTIONS
4. INHOMOGENEOUS ISOMER SHIFT
5. MAGNETIC DIPOLAR INTERACTIONS
6. RESONANCE BROADENING VIA ELECTROSTATIC INTERACTION

FIGURE 3.- SOURCES OF LINE BROADENING IN ISOMERIC TRANSITIONS.



Figure—4 A Typical Source—Absorber Configuration for a Mossbauer Gravitometer.

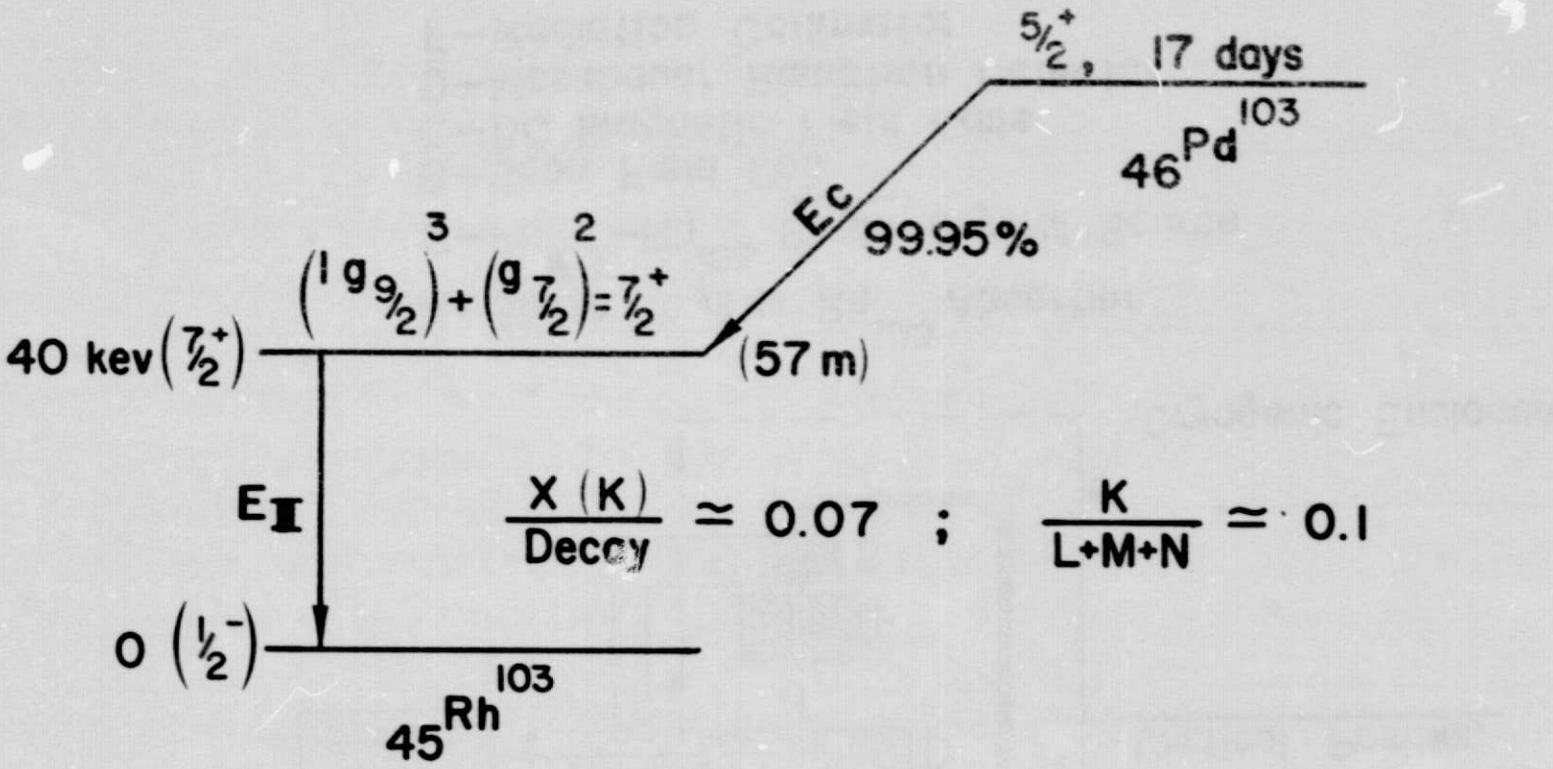
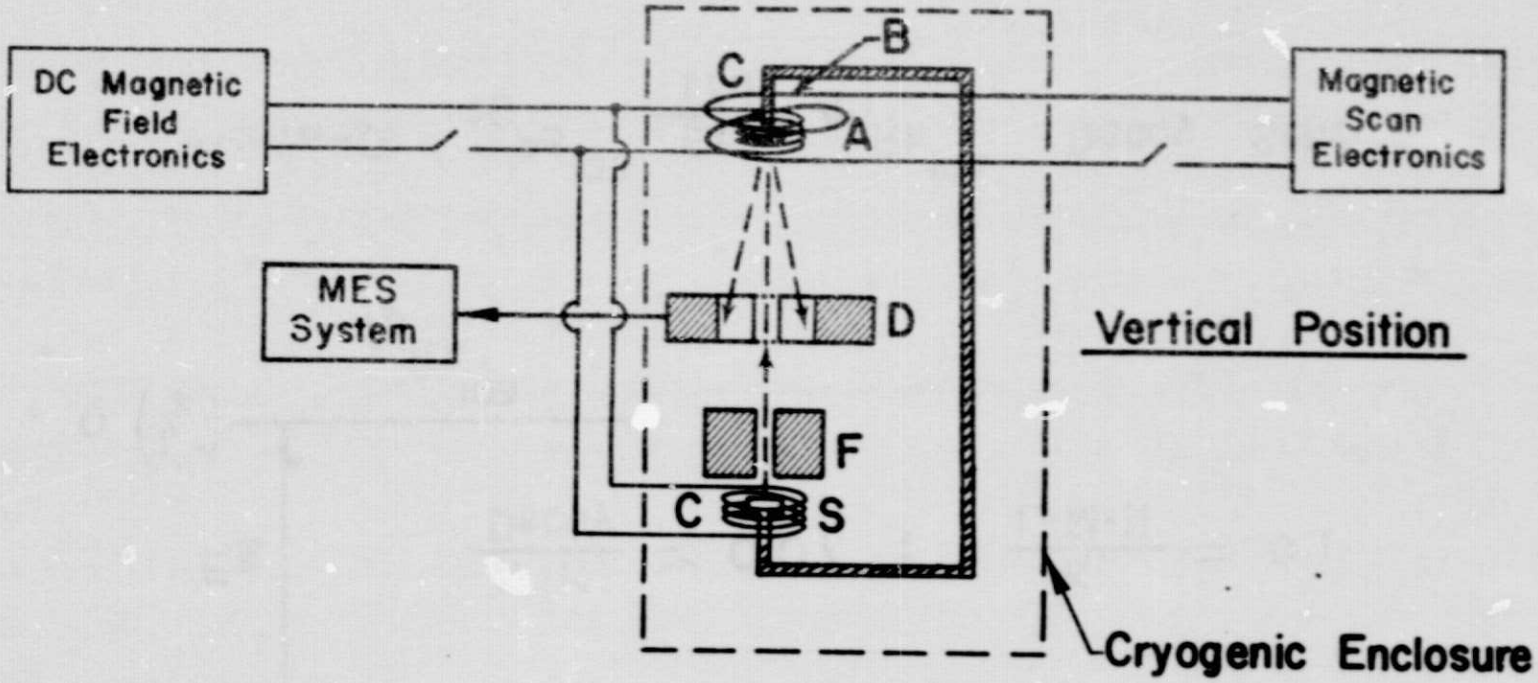


Figure-5 $_{46}Pd^{103} \xrightarrow[17d]{Ec} {}_{45}Rh^{103}$ Decay Scheme



A – Single Crystal Rh^{103} Absorber
S – Pd^{103} – Rh^{103} Single Crystal Source
B – Scan Field Coil
C – DC Magnetic Field Coils
D – Mossbauer Radiation Detector
F – Radiation Collimator

Figure – 6. Schematic experimental arrangement for a Mossbauer gravitometer.